ANALYSIS OF OPTICAL BEAT INTERFERENCE IN SUBCARRIER MULTIPLEXED LIGHTWAVE SYSTEMS

by

V. S. SRIKANTH

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ANALYSIS OF OPTICAL BEAT INTERFERENCE IN SUBCARRIER MULTIPLEXED LIGHTWAVE SYSTEMS

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CERTIFICATE

It is certified that the work contained in the thesis entitled "*Analysis of Optical beat interference in Subcarrier Multiplexed Lightwave systems*", by "*V.S. Srikanth*", has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Pradip Sircar

Dr. Pradip Sircar 10 Jul 1992

Assistant professor,
Department of Electrical Engineering,
Indian Institute of Technology, Kanpur.

July 1992.

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ABSTRACT

Optical beat interference occuring in a Subcarrier Multiplexing system using many optical carriers is analysed. For the case of intensity modulation of optical sources, interference noise's power spectrum is derived. Effect of laser line shape, line width, number of modes are studied. To study the effect of uncertainty of wavelength on performance of system, analytical approach is adopted for the cases of 2 single mode and 2 multimode laser. Simulation strategy is adopted for the more complex case of system having many multilongitudinal mode semiconductor lasers.

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Srikanth.

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CHAPTER 1

INTRODUCTION

The objective of any communication system is the transfer o
information from one point to another. The information transfer i
accomplished in most cases by modulating the information onto
carrier and subsequent transmission and demodulation. An optica
communication channel uses carriers whose frequency is severa
orders of magnitude higher than their radio_frequency or Microwav
counterparts. This increases the available transmission bandwidt
and hence the information capacity of the channel.

The major application area for lightwave technology is multipl
access systems which include local and metropolitan area networks
There are two methods of providing multiple access to the sam
space channel according to their operational description in eithe
time or spectral domain. The methods are

1) Time Division Multiple Access (TDMA)

2) Spectral Division Multiple Access (SDMA)

In the following paragraphs suitability of these methods ar
discussed.

TDMA:

Unlike in the case of wideband links, in multiple access systems, each user generally requires only a small fraction of total data throughput. In TDMA this fraction is time division multiplexed into a high bit rate data stream and hence the difference with wideband links is not taken into advantage. Each receiver has to receive all the transmitted data and select appropriate bits. This requires high speed demultiplexers and wideband receivers. As receiver sensitivity decreases with increasing bandwidth TDMA systems are often limited to low data throughput rates or a small number of users.

SDMA:

This is an alternative way of bandwidth utilisation in which the operations are done in spectal domain rather than in the time domain. SDMA can be implemented in two ways:

1) Optical Frequency Division Multiplexing (OFDM)

2) Subcarrier Multiplexing (SCM)

OFDM:

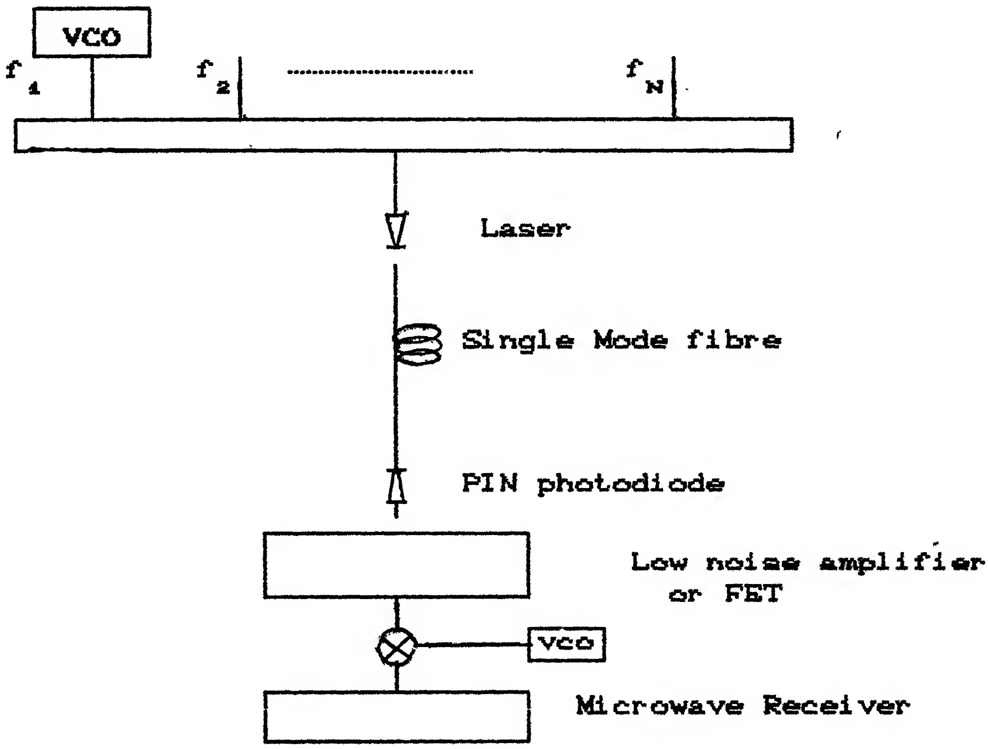
In these systems the multiplexing and demultiplexing/channel selection functions are carried out in the optical domain. It is required that the radiation generated should be strictly single mode. Temperature stabilisation and wavelength control are needed. This generally involves sophisticated coherent lightwave

technologies. This mode of implementation is not very cost_effective at present.

SCM:

This is a two stage modulation scheme, in which the message signals in some suitable manner modulate intermediate carriers called subcarriers. The composite signal is used to modulate the main carrier.

The block diagram of an SCM lightwave system is shown in the following figure.



fig(1). A SCM Lightwave system

A large no., of modulated microwave carrier frequencies f_i are combined in a microwave power combiner and composite signal is used to modulate the intensity of a Semiconductor laser. The intensity modulated signal is transmitted over a single mode fibre and directly detected with a wideband InGaAs PIN photodiode. The desired narrowband channel has to be amplified and demodulated using conventional microwave techniques. The receiver photocurrent can be amplified with either a wideband low noise amplifier or a wideband PIN-FET Receiver.

For a subscriber distribution system, where only a single channel needs to be selected for demodulation a tunable local oscillator mixer and narrowband filter can be used to select simultaneously desired SCM channel and down convert into a more cnonvenient intermediate frequency. The IF signal is then passed to an appropriate demodulator, which recovers baseband signal.

Advantages of SCM:

1) Wideband amplification and high speed demultiplexing are not required and the receiver sensitivity is determined by the bandwidth of one channel only. Resulting increase in sensitivity can increase number of allowed users.

2) Spectral characteristics of each soruce are unimportant so that multimode lasers can be used. Temperature stabilisation or wavelength control is not needed.

3) The flexibility in allocation of bandwidth and indifference to the choice of modulation format makes SCM very attractive for broadband applications where services may originate from a variety of different service provider each preffering a different modulation format and requiring different signal bandwidths.

4) The scheme is capable of simultaneous transmission of conventional baseband signals using the same laser, fibre and detector.

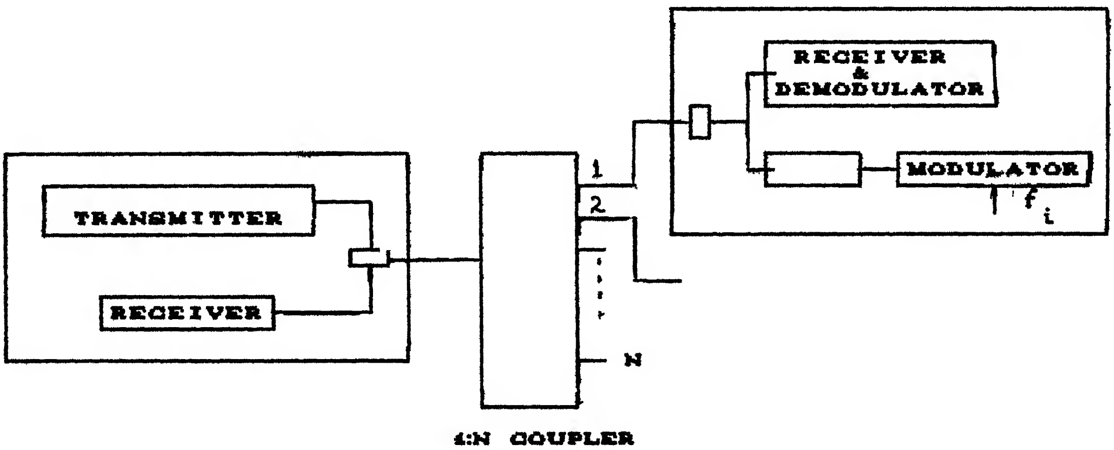
5) As each channel is continuously available and independent of all other channels a variety of network architectures and access protocols are possible. There is no need for synchronisation between each channel and a high speed master network clock.

Purpose of this work:

SCM can be applied in a passive local area network where N users are interconnected via a passive N X N star coupler such that each user can communicate with any other. Also SCM can be used in a local loop, in which a single shared fibre is used to service N customers via a passive optical coupler as shown infig(2). In the down strean direction various services (voice,data,video) can be provided on different subcarrier frequencies. In the upstrean direction, Subcarrier modulation is used by each customer usingdifferent optical sources. In such

applications involving multiple optical carriers mixing of optical carriers takes place at the shared photodetector giving rise to interference noise. This interference may limit the number of optical carriers or the transmission bandwidth carried by each source.

The purpose of this work is to analyse the limitations caused by optical interference in systems having 2 Single mode lasers to N Multimode lasers. In a practical network, optical sources would have centre wavelengths distributed over a broad range of wavelengths. Another aim of this study is to analyse the effect of this on the channel capacity.



fig(2). A Bidirectional Optical SCM system

Literature Survey:

Darcie's paper 'Subcarrier Multiplexing for Multiple Access Lightwave Networks' [1]kindled the interest in SCM optical Communication systems. This paper discussed about the application of SCM to Lightwave Multiple Access Networks. It was shown how available microwave and lightwave components can be used, in SCM to provide high capacity networks. It was shown that SCM provided a relatively simple means to multiplex while maintaining high receiver sensitivity which opened the possibility of interconnection of a large number of users. A Multiple Access Network was proposed that could support 1024 users at a continuous bit rate of 1.5 MBits/user.

Olshanky & Lanziera (1987) [2] carried out a 60 channel FM video transmission experiment. The 60 channels spanned a band 2.7-5.2GHz. The composite signals were used to modulate directly a 1.3μm Laser biased a 5mw. The signals were propagated over 18km of single mode fibre. A 56dB weighted SNR was obtained with 2% modulation depth/channel and a corresponding 16.5dB CNR.

In [3] it was shown that when multiple optical carriers were used in an SCM system, the mixing of optical field in the photodetector resulted in interference noise which limited the maximum number of channel or the bandwidth of SCM.

The analysis presented in[3] was extended to the case of multilongitudinal mode lasers in [4]. Also results of a statistical analysis to study random distribution of wavelength of semiconductor laser was presented.

[5] presented a general model of optical beat interference (OBI) and its contribution to channel outage in a WD-SFDMA Networks. The probability of channel outage due to OBI was determined from analysis and computer simulation for externally and directly modulated single mode lasers.

Thesis Layout:

Chapter 2 discusses about the general OBI problem. Power spectrum of interference noise when, two single mode lasers are intensity modulated are derived for both Gaussian as well as Lorentian spectras. This analysis is extended for 2 multimode as well as N number of multimode lasers.

Chapter 3 deals with the effect of random wavelength distribution of optical sources on channel capacity. Analytical expressions for probability of achieving a given SIR are got for simple cases of 2 single mode as well as 2 multimode Lasers. Simulation study for the case of N multimode lasers is also presented.

Chapter4 discusses about inferences and future scope of work.

CHAPTER 2

OPTICAL BEAT INTERFERENCE

Optical beat interference (OBI) is caused when two or more lasers transmit over the same optical channel and the combined signal is detected by the shared photodetector. Because of the square law nature of photodetection process, generated photocurrent contains cross mixing terms or beating notes at the difference frequencies corresponding to each pair of optical fields. The resulting noise is termed 'Interference Noise'. In case some beat frequencies overlap a subcarrier channel, the signal to interference ratio (SIR) is degraded.

In this chapter, optical mixing of stationery uncorrelated sources is considered first. Next, the case of two single mode longitudinal lasers which are intensity modulated is dealt with. Derived results are extended for the more complex case of N number of multilongitudinal mode lasers.

Section A:

Optical Mixing of Stationery Uncorrelated Sources

The electric fields incident on the photodetector are assumed to have different optical frequencies ν_1 and ν_2. The electric fields expressed in terms of analytical signals and complex envelopes are

$$E_1(t) = \mathrm{Re}\langle E_1(t)\rangle = \mathrm{Re}\langle \tilde{E}_1(t).e^{j2\pi\nu_1 t} \rangle \qquad (2.A.1)$$

$$E_2(t) = \mathrm{Re}\langle E_2(t)\rangle = \mathrm{Re}\langle \tilde{E}_2(t).e^{j2\pi\nu_2 t} \rangle \qquad (2.A.2)$$

where E_i's are Real fields,

E_i's are Analytical signals, and

$\tilde{E}_i$'s are Complex Envelopes.

Optical Intensity incident on the detector,

$$I'(t) \propto (E_1(t) + E_2(t))^2$$

$$= k (E_1^2(t) + E_2^2(t) + 2.E_1(t).E_2(t)) \qquad (2.A.3)$$

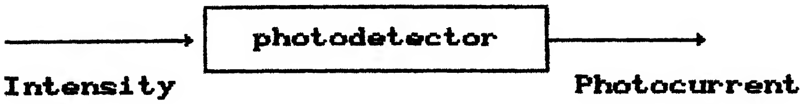
Defining $I(t) \triangleq I'(t)/k$,

$$I(t) = I_1(t) + I_2(t) + I_x(t) \qquad (2.A.4)$$

where $I_i(t) = E_i^2(t)$ $\quad i = 1,2$ are the direct detection intensity components and

$I_x(t) = 2.E_1(t).E_2(t)$ is heterodyne mixing cross term.

fig.3 shows transducer property of Photodetector.



$$I(t) \qquad\qquad h_D(t) \qquad\qquad i^D(t) = I(t) \otimes h_D(t) \qquad (2.A.5)$$

fig 3. Transducer property of photodetector

$h_D(t)$ is the detector impulse response [7]. The travel time of each generated electron is finite, hence the function $h_D(t)$ must be time limited to some finite interval τ_h. The bandwidth of photodetector is inversely related to τ_h. Here the bandwidth of photodetector is assumed to have a cutoff frequency which is much lower than optical frequency.

The heterodyne cross term can be expressed in the following way.

$$I_x(t) = 2.\ E_1(t)E_2(t)$$

$$= 2.\ \left[\frac{E_1(t) + E_1^*(t)}{2}\right]\left[\frac{E_2(t) + E_2^*(t)}{2}\right]$$

$$I_x(t) = \left[\frac{E_1(t)E_2(t) + cc}{2} \right] + \left[\frac{E_1(t)E_2^*(t) + cc'}{2} \right]$$

where cc and cc′ are complex conjugates of respective terms.

$$= \mathrm{Re}\langle E_1(t)E_2(t) \rangle + \mathrm{Re}\langle E_1(t)E_2^*(t) \rangle$$

$$= \mathrm{Re}\langle \tilde{E}_1(t)\tilde{E}_2(t).e^{j2\pi(\nu_1 + \nu_2)t} \rangle$$

$$+ \mathrm{Re}\langle \tilde{E}_1(t)\tilde{E}_2^*(t).e^{j2\pi\Delta\nu t} \rangle \qquad (2.A.6)$$

$$\text{where } \Delta\nu \triangleq \nu_1 - \nu_2 \qquad (2.A.7)$$

If $i_x^D(t)$ is the photocurrent due to heterodyne cross term,

$$i_x^D(t) = h_D(t) * I(t) \qquad (2.A.8)$$

Under the following assumption,

$$\Delta\nu < \text{Bandwidth of Photodetector} < \nu_1 + \nu_2 \qquad (2.A.9)$$

difference frequency term of Eq.(2.A.6) is filtered through and the sum frequency term is filtered out. Hence,

$$i_x^D(t) = \mathrm{Re}\langle \tilde{E}_1(t)\tilde{E}_2^*(t).e^{j2\pi\Delta\nu t} \rangle \qquad (2.A.10)$$

Autocorrelation of mixing term is,

$$\Gamma_{i^D}(\tau,t) = \langle i_x^D(t + \tau)i_x^D(t) \rangle \qquad (2.A.11)$$

Using the relation,

$$\mathrm{Re}\langle A\rangle \mathrm{Re}\langle B\rangle = \frac{1}{2}\mathrm{Re}\langle AB\rangle + \frac{1}{2}\mathrm{Re}\langle AB^*\rangle \qquad (2.A.12)$$

$$\Gamma_{i_x^D}(\tau,t) = \frac{1}{2}\,\mathrm{Re}\langle\ \langle\ \tilde{E}_1(t+\tau)\tilde{E}_2^*(t+\tau)\tilde{E}_1^*(t)\tilde{E}_2(t)\rangle e^{j2\pi\Delta\nu\tau}\rangle$$

$$+\ \frac{1}{2}\,\mathrm{Re}\langle\ \langle\ \tilde{E}_1(t+\tau)\tilde{E}_2^*(t+\tau)\tilde{E}_1^*(t)\tilde{E}_2(t)\rangle e^{j2\pi\Delta\nu(2t+\tau)}\rangle \tag{2.A.13}$$

In case $\tilde{E}_1(t)\tilde{E}_2^*(t)$ is wide sense stationary the first term depends only on τ second term on both τ and t. Under these type of nonstationary conditions the statistical ensemble average should be generalised to a combination of both ensemble and time averaging [9] which causes second term to vanish.

Assuming $E_1(t)$ & $E_2(t)$ independent, and hence using the property that the mean of product of random independent processes is equal to the product of means.

$$\Gamma_{i_x^D}(\tau) = \frac{1}{2}\,\mathrm{Re}\langle\ \langle\tilde{E}_1(t+\tau)\tilde{E}_1^*(t)\rangle\langle\tilde{E}_2(t+\tau)\tilde{E}_2^*(t)\rangle^* e^{j2\pi\Delta\nu\tau}\ \rangle \tag{2.A.14}$$

The terms in the $\langle\ \rangle$'s are auto correlation of complex envelop of incident electric fields i.e.,

$$\Gamma_{i_x^D}(\tau) = \frac{1}{2}\,\mathrm{Re}\langle\ \tilde{\Gamma}_{E_1}(\tau)\tilde{\Gamma}_{E_2}^*(\tau)e^{j2\pi\Delta\nu\tau}\ \rangle$$

$$= \frac{1}{2}\,\mathrm{Re}\langle[\ \tilde{\Gamma}_{E_1}(\tau)e^{j2\pi\nu_1\tau}][\ \tilde{\Gamma}_{E_2}(\tau)e^{-j2\pi\nu_2\tau}]\rangle$$

$$= \frac{1}{2}\,\mathrm{Re}\langle\ \Gamma_{E_1}(\tau)\Gamma_{E_2}^*(\tau)\ \rangle$$

$$= \frac{1}{4}[\ \Gamma_{E_1}(\tau)\Gamma_{E_2}^*(\tau) + cc] \tag{2.A.15}$$

Fourier Transforming,

$$S_{i_x D}(f) = \frac{1}{4}[\, S_{E_1} * S_{E_2}](f) + \frac{1}{4}[\, S_{E_1} * S_{E_2}](-f) \qquad (2.A.16)$$

where * denotes correlation.

In Eq. (2.A.16) the second term is an inverted version of first term and hence, power spectra is an even function of frequency. Eq. (2.A.16) is rewritten as,

$$S_{i_x D}(f) = \frac{1}{4}\Big[\, S_{E_1}(f) * S_{E_2}(f)] + [\, S_{E_2}(f) * S_{E_1}(f) \Big] \qquad (2.A.17)$$

This above procedure is applied for the case of signal spectra centred around different frequencies, the photocurrent spectra got is two sided and centred around the difference frequencies. First and second term yield +ve & -ve halves of spectrum respectively.

Fig 4 gives a relationship between power spectrum of photocurrent and power spectra of mixing optical Electric fields.

Intuitive interpretation of Lineshape correlation:

Even under the condition of mutual incoherence of two interfering beams, each of them can be considered to be made up of a number of quaasimonochromatic components having high degree of coherence. A beat signal is generated by a pair of such components. Superposition of such signals on an intensity basis yields the output spectrum.

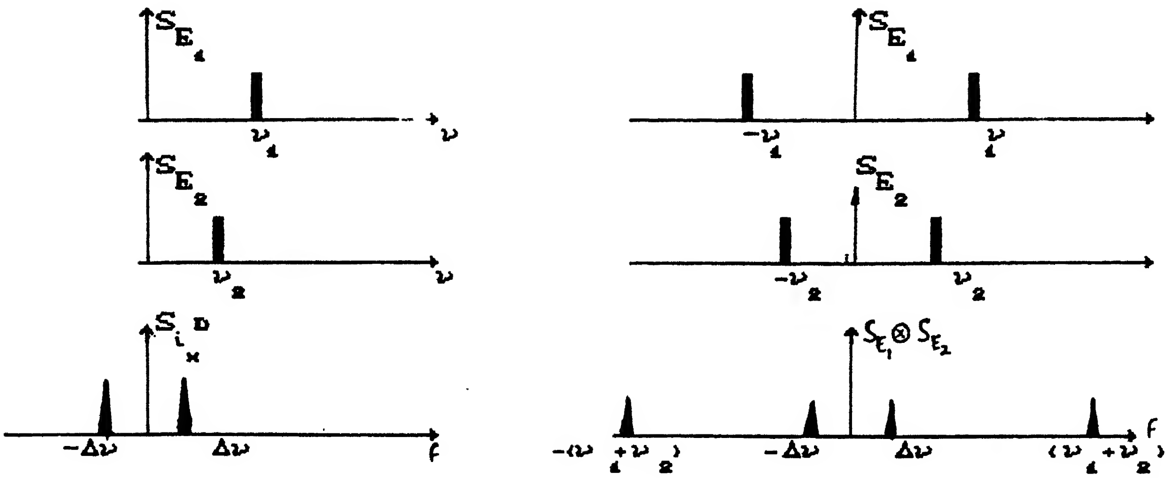


Fig 4. Relationship between power spectra of photocurrent and power spectra of mixing optical electric fields.

The output photocurrent spectrum is given by Eq. (2.A.17).

$$S_{i_x^D}(f) = \frac{1}{4}[\, S_{E_1}(f) * S_{E_2}(f)] + [\, S_{E_2}(f) * S_{E_1}(f)]$$

$$= \frac{1}{4}\int_{-\infty}^{\infty} [S_{E_1}(f + \nu)\, S_{E_2}(f) + S_{E_2}(f + \nu)\, S_{E_1}(f)]d\nu \qquad (2.A.18)$$

Interpreting 'f' as the setting of a narrowband tunable filter of spectrum analyser, there will be contributions from all pairs of lines which are set 'f' apart in the two signals. i.e., for each value 'ν' of optical frequency the component $E_{1(2)}$ at frequency 'ν + f' beats with component of $E_{2(1)}$ respectively at frequency 'ν' to generate a contribution of strength $S_{E_1}(f + \nu)S_{E_2}(f)[S_{E_1}(f + \nu)S_{E_2}(f)]$. The Integral represents superposition of all combinations.

Section B:

Optical Mixing of Intensity Modulated Sources.

In this analysis transmission degradation due to fibre is completely ignored. $P_1(t)$ & $P_2(t)$ are two message signals intensity modulating two separate optical carriers with same polarisation states. The two signals are combined through a passive optical coupler and then detected by a Photodetector. The combined Electric field incident on the photodetector is

$$e(t) = \sqrt{P_1(t)}.\ E_1(t) + \sqrt{P_2(t)}.\ E_2(t) \qquad (2.B.1)$$

$$P_i(t) = 1 + m_i(t)\mathrm{Cos}2\pi f_i t \qquad (2.B.2)$$

where $E_i(t)$ represents Electric field of optical carrier and $m_i(t)$ represents the messages modulating the subcarriers with frequency f_i. The photodetector current is proportional to low frequency component of square of modulus of electric field $e(t)$

$$i(t) \ \alpha \ \langle \ |e(t)|^2 \rangle$$

$$= P_1(t) + P_2(t) + \langle\ 2\sqrt{P_1(t)P_2(t)}\ .E_1(t)E_2(t)\rangle \qquad (2.B.3)$$

$\langle \quad \rangle$ represents low frequency part.

Electric fields intensities are normalised to unity. $P_1(t)$ and $P_2(t)$ represent the modulated subcarrier signals occupying different frequency bands. The term in { } represents the mixing term and if it lies within the bandwidth of desired signals it acts as undesired interference component.

In the absence of any modulation a single longitudinal mode semiconductor laser's linewidth is very narrow (around 10MHz). But, application of direct intensity modulation results in a large broadening of laser spectrum(around GHz). In the analysis it is assumed that the message bandwidth is very small compared to linewidth of lasers. Under these conditions mixing term's current contribution can be written as,

$$i_x(t) \propto \{ 2.E_1(t)E_2(t)\} \qquad (2.B.4)$$

Proceeding in the same manner as outlined in Section A, spectrum of mixing term part of photocurrent

$$S_{i_x D}(f) = \frac{1}{4}[\ S_{E_1} * S_{E_2}\ ](f) + \frac{1}{4}[\ S_{E_1} * S_{E_2}\ ](-f) \qquad (2.B.5)$$

In the following section the two cases of line spectra for lasers i.e., Lorentian and Gaussian are considered.

Section C:

Effect of Laser power spectral shapes.

1) Lorentian spectra:

Normalised Power spectral density for Lorentian spectra is given by [11],

$$\hat{S}(f) = \frac{2(\pi\Delta\nu)^{-1}}{1 + \left[2\left(\frac{f - \bar{\nu}}{\Delta\nu}\right)\right]^2} \qquad (2.C.1)$$

where $\bar{\nu}$ is central frequency and $\Delta\nu$ is half power bandwidth.

from Eq. (2.B.5)

$$S_{i_x D}(f) = \frac{1}{4}[\, S_{E_1} * S_{E_2} \,](f) + \frac{1}{4}[\, S_{E_1} * S_{E_2} \,](-f) \qquad (2.C.2)$$

$$= \frac{1}{4}[F[\, \Gamma_{E_1}(\tau).\Gamma_{E_2}^{*}(\tau) \,] + F[\, \Gamma_{E_2}(\tau).\Gamma_{E_1}^{*}(\tau) \,]\,] \qquad (2.C.3)$$

Using the relations, [8]

$$e^{-|\tau|} \rightleftarrows \frac{2}{1 + (2\pi f)^2} \qquad (2.C.4)$$

where $\rightleftarrows$ denotes fourier transform pair..

If $g(\tau) \rightleftarrows G(f)$ then,

$$g(a\tau) \rightleftarrows \frac{1}{|a|} G\left(\frac{f}{a}\right) \qquad (2.C.5)$$

$$g(\tau)e^{j2\pi f_o \tau} \rightleftarrows G(f - f_o) \qquad (2.C.6)$$

$$\Gamma_E(\tau) = e^{-|\tau\pi\Delta\bar{\nu}|}\, e^{-j2\pi\nu\tau} \rightleftarrows \frac{2(\pi\Delta\nu)^{-1}}{1 + \left[\dfrac{2\pi(f - \bar{\nu})}{\pi\Delta\nu}\right]^2} \qquad (2.C.7)$$

$$\therefore \Gamma_{E_1}(\tau)\Gamma^*_{E_2}(\tau) = e^{-|\tau|\pi(\Delta\nu_1 + \Delta\nu_2)} \,.\, e^{-j2\pi\tau(\nu_1 - \nu_2)} \qquad (2.C.8)$$

$$F[\Gamma_{E_1}(\tau)\Gamma^*_{E_2}(\tau)] = \frac{2(\pi(\Delta\nu_1 + \Delta\nu_2))^{-1}}{1 + \left[2\left(\dfrac{f - (\nu_1 - \nu_2)}{(\Delta\nu_1 - \Delta\nu_2)}\right)\right]^2} \qquad (2.C.9)$$

$$= \frac{2}{\pi(\Delta\nu_1 + \Delta\nu_2)} \times \frac{1}{1 + \left[2\left(\dfrac{f - (\nu_1 - \nu_2)}{(\Delta\nu_1 - \Delta\nu_2)}\right)\right]^2} \qquad (2.C.10)$$

$$F[\Gamma_{E_2}(\tau)\Gamma^*_{E_1}(\tau)] = \frac{2}{\pi(\Delta\nu_1 + \Delta\nu_2)} \times \frac{1}{1 + \left[2\left(\dfrac{f - (\nu_2 - \nu_1)}{(\Delta\nu_1 - \Delta\nu_2)}\right)\right]^2} \qquad (2.C.11)$$

$$S_{i_x D}(f) = \frac{1}{4} \times \frac{2}{(\pi\Delta\nu)} \times \left[\frac{1}{1 + \left[2\left(\dfrac{f - \delta\nu}{\Delta\nu}\right)\right]^2} + \frac{1}{1 + \left[2\left(\dfrac{f + \delta\nu}{\Delta\nu}\right)\right]^2}\right]$$

(2.C.12)

where resulting linewidth $\Delta\nu \triangleq \Delta\nu_1 + \Delta\nu_2$

$$\& \quad \delta\nu \triangleq \nu_1 + \nu_2$$

Each of these individual components are Lorentian, centre frequencies of which are $(\nu_1-\nu_2)$ & $(\nu_2-\nu_1)$ and the linewidth remaining same equals $(\Delta\nu_1 + \Delta\nu_2)$.

Suppose Bandwidth of interest is 'B' such that $0 < f < B$ then the total interference power is got by integrating Eq. (2.C.12) over appropriate interval. It is seen that the spectrum does not varymuch if 'B' is very small compared to optical frequencies. In this case the power spectrum is assumed to be constant over the choosen band and its value equals that at f=0. Power spectrum of interference noise within the specified band is

$$F(\delta\nu) = \frac{2}{(\pi\Delta\nu)} X \frac{1}{1 + \left[\dfrac{2\delta\nu}{\Delta\nu}\right]^2} \qquad (2.C.13)$$

It is important to note that for the above calculations, message is assumed to be in the baseband. To account for subcarrier frequency 'f_i' in Eq (2.C.13) $\delta\nu$ is replaced by $(\delta\nu - f_i)$. Signal to interference ratio i.e., SIR in dB is given by

$$SIR = 10\log\left[\frac{\frac{1}{2}\langle m_i^2(t)\rangle}{F(\delta\nu)B}\right] \qquad (2.C.14)$$

where $\frac{1}{2}\langle m_i^2(t)\rangle$ represents the detected average message power. For calculations it is assumed to be equal to $\frac{1}{2}$ (for modulation depth 100%). The denominator represents interference noise in the message bandwidth.

2) Gaussian Line spectra:

Normalised Power spectral density for Gaussian spectra is given by [11],

$$\hat{S}(f) = \frac{2}{\Delta\nu}\sqrt{\frac{\ln 2}{\pi}}\exp\left[-\left(\frac{2}{\Delta\nu}\sqrt{\frac{\ln 2}{1}}(f - \bar{\nu})\right)^2\right] \qquad (2.C.15)$$

Since, $\exp(-\pi\tau^2) \rightleftarrows \exp(-\pi f^2)$

$$\Gamma_{E_i}(\tau) = F^{-1}\{\hat{S}_{E_i}(f)\} = \exp\left[-\pi\left(\frac{\tau}{2}\sqrt{\frac{\pi\Delta\nu}{\ln 2}}\right)^2\right].\exp(j2\pi\tau\bar{\nu}_i) \qquad (2.C.16)$$

From Eq. (2.C.2),

$$S_{i_{x}D}(f) = \frac{1}{4}[S_{E_1} * S_{E_2}](f) + \frac{1}{4}[S_{E_1} * S_{E_2}](-f)$$

$$= \frac{1}{4}[F[\Gamma_{E_1}(\tau).\Gamma_{E_2}^*(\tau)] + F[\Gamma_{E_2}(\tau).\Gamma_{E_1}^*(\tau)]] \qquad (2.C.17)$$

$$[F[\Gamma_{E_1}(\tau).\Gamma_{E_2}^*(\tau)] = \frac{2\sqrt{\ln 2}}{\sqrt{\pi[(\Delta\nu_1)^2 + (\Delta\nu_2)^2]}} \times$$

$$\exp -\pi\left[\frac{2\sqrt{\ln 2}}{\sqrt{\pi[(\Delta\nu_1)^2 + (\Delta\nu_2)^2]}}\frac{(f - (\nu_1 - \nu_2))}{}\right]^2$$

$$[F[\Gamma_{E_2}(\tau).\Gamma_{E_1}^*(\tau)] = \frac{2\sqrt{\ln 2}}{\sqrt{\pi[(\Delta\nu_1)^2 + (\Delta\nu_2)^2]}} \times$$

$$\exp -\pi\left[\frac{2\sqrt{\ln 2}}{\sqrt{\pi[(\Delta\nu_1)^2 + (\Delta\nu_2)^2]}}\frac{(f - (\nu_2 - \nu_1))}{}\right]^2 \quad (2.C.19)$$

$$\left.\begin{array}{l}\text{Defining } \Delta\nu \triangleq \sqrt{(\Delta\nu_1)^2 + (\Delta\nu_2)^2} \\ \& \quad \delta\nu = \nu_1 - \nu_2\end{array}\right] \quad (2.C.20)$$

Mixing term of photocurrent's spectrum is,

$$S_{i_x^D}(f) = \frac{1}{4}\left[\frac{2\sqrt{\ln 2}}{\sqrt{\pi}\ \Delta\nu}\left\{\exp\left(-\pi\left[\frac{2\sqrt{\ln 2}}{\sqrt{\pi}\ \Delta\nu}(f - \delta\nu)\right]^2\right) + \right.\right.$$

$$\left.\left.\exp\left(-\pi\left[\frac{2\sqrt{\ln 2}}{\sqrt{\pi}\ \Delta\nu}(f + \delta\nu)\right]^2\right)\right\}\right] \quad (2.C.21)$$

For getting the power spectrum of interference noise within the specified band (say baseband) same approximations as applied in case of Lorentian spectra are used. The power spectrum of interference noise is,

$$F(\delta\nu) = \frac{2 \times 0.47}{\Delta\nu} . \exp -\left[\frac{2. \ \delta\nu}{1.2 \ \Delta\nu}\right]^2 . \qquad (2.C.22)$$

3) Case study : Single longitudinal mode lasers.

Fig(5) shows how the SIR varies for various spectral widths, as the difference frequency changes. Receiver Bandwidth is assumed to be 5MHz.

1) At low frequency differences SIR is very small which is due to noise spectrum centring essentially over the baseband. As the difference frequency increases, the interference power sectrum shifts towards higher frequencies and hence noise power in the receiver Bandwidth is reduced.

2) Due to sharper roll off nature of Gaussian spectra, reduction of noise as difference frequency is increased is much more as compared to Lorentian spectra. Hence SIR increases more rapidly in case of Gaussian spectra.

3) Increase of linewidth causes reduction in SIR. This is due to spreading of noise and hence increase of total noise in the Receiver Bandwidth.

Section D:

<u>Multilongitudinal Mode Lasers</u>

Lasers always tend to oscillate on many modes. This is due to the fact that the mode separation is usually much smaller than the gain profile.

Multimodes can occur for homogeneous as well as inhomogeneous lines. For a homogeneous line, occurrrence is due to holes burned in the Spatial distribution of inversion within the active material(Spatial Hole burning). For an inhomogeneous line, Multimode oscillation is due to both Spatial hole burning and Frequency hole burning (holes burned in the gain curve) [10]

In this analysis it is assumed that the modes oscillate independently without appreciable degree of phase locking.[11] Multimode lasers are modelled as a sum of individual longitudinal modes separated from each other by fixed wavelength. Spectral shapes of each are of same type and the phases are assumed to be uncorrelated. Mixing of all possible combinations is taken into account for the calculation of noise.

<u>Case study: Multimode lasers</u>

Fig(6) shows the variation of SIR as a function of difference frequency of optical sources. The Multimode Laser has 3 modes each of linewidth 10GHZ. Envelope of Mode Power spectra is assumed to

be Gaussian with half power width of 5nm. From the graph following salient features are noted.

1) As the separation is increased SIR increases at first and then decreas es at intervals equalling the mode separation. This is due to identical wavelength of some modes and hence the resulting beating causing maximum noise contribution.

2) Compared to Single mode laser case, SIR is higher in this case. This is due to the assumption that longitudinal modes are uncorrelated and hence the noise contributions for different modes adding on a power basis.

Section E:

<u>Multiple Optical Sources:</u>

Lasers with Identical wavelength:

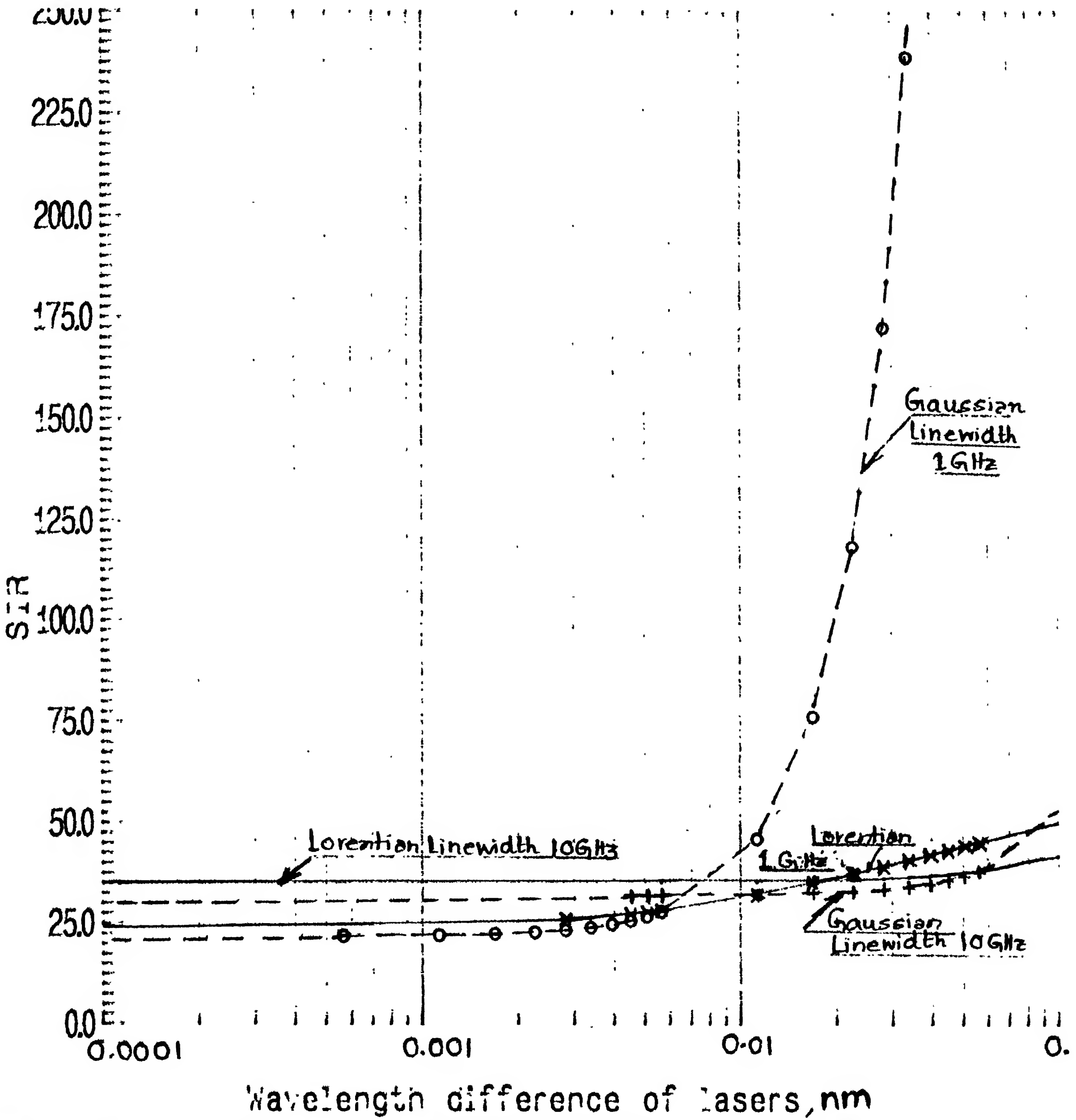
Assuming there are N optical carriers present (N > 2); there are $(N^2-N)/2$ interference terms representing the mixing of all possible combinations. In the worst case of all the sources being identical (same spectra, same λ & same power)

$$SIR_N = SIR|_{\delta f=0} - 10\log\left[\frac{N^2 - N}{2}\right] \qquad (2.E.1)$$

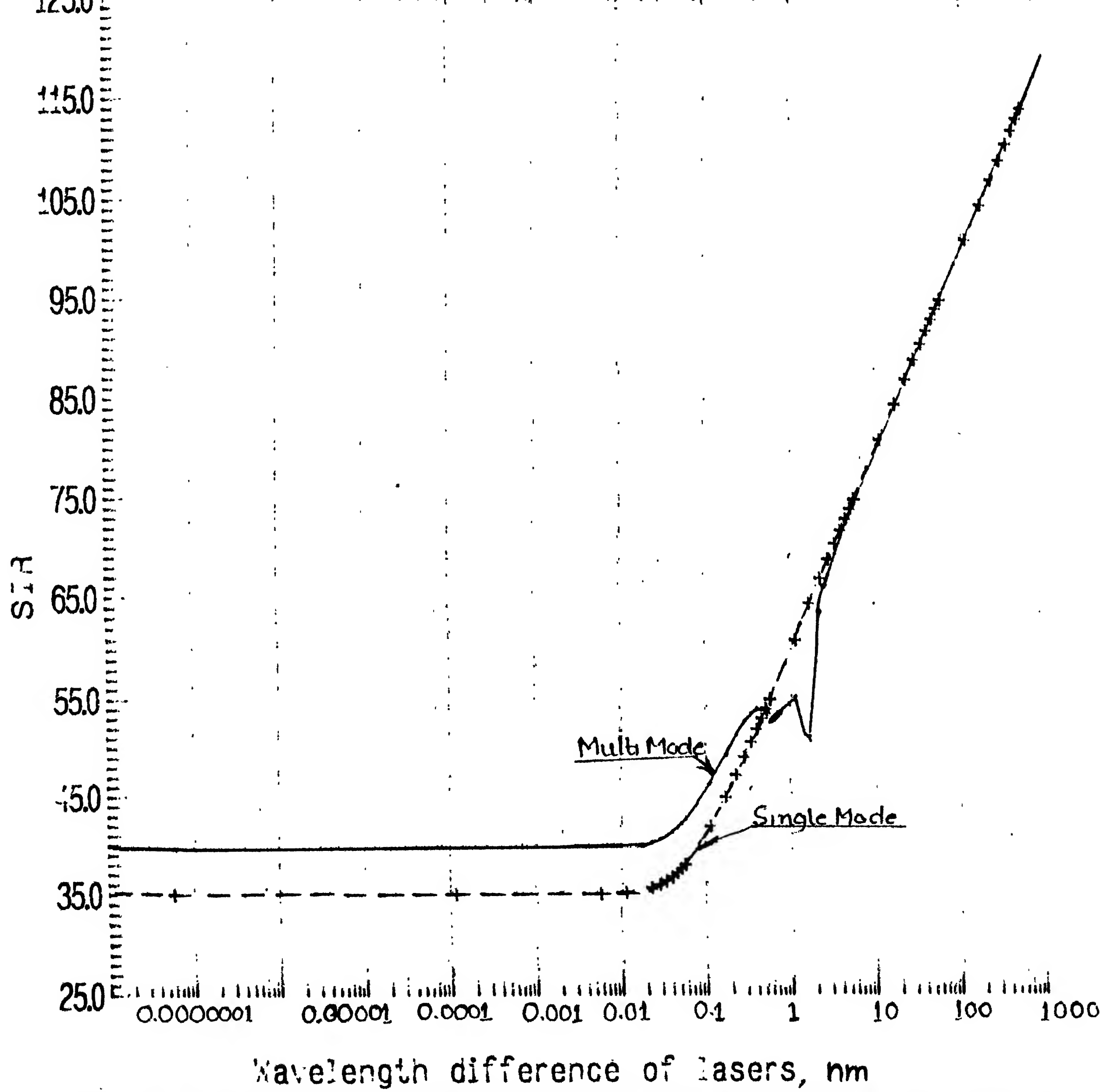
Lasers with different wavelengths:

It is more realistic to assume different operating wavelength of Lasers. Under this case the noise contribution will be less than that for the identical wavelength case hence SIR improves. Considering simplest case of 'N' single longitudinal mode Lasers separated by fixed wavelengths and assuming that the interference is the result of mixing of only adjacent carriers, there are only N - 1 interference terms and hence

$$SIR_N = SIR|_{\delta f} - 10\log(N - 1) \qquad (2.E.2)$$



VARIATION OF SIR WITH WAVELENGTH DIFFERENCE OF MONOMODE LASERS



SIR VS WAVELENGTH DIFFERENCE COMPARISON BETWEEN MONOMODE AND MULTIMODE LASERS

CHAPTER 3

RANDOM NATURE OF WAVELENGTHS OF LASERS

In the system performance evaluation of lightwave networks itis more reasonable to assume that the centre wavelengths of semiconductor lasers are randomly distributed over a range of wavelengths. Uncertainty of wavelengths arises due to following factors

1) Different lasers have different characteristics, and the type of laser being used at the transmitter end may not be known.

2) Even if type of the transmitting laser is known, wavelength can be uncertain due to temperature variations and short term and long term changes in the laser characteristics.

In case of systems, in which all the lasers are designed to operate at a particular wavelength the centre wavelength may be distributed within a range Therefore, for given channel bandwidth, and N randomly chosen sources, the system may not achieve a desired signal to interference noise ratio (SIR).

There are two approaches for evaluating system performance. Section A discusses about the analytical approach wherein, the

probability density function (PDF) of interference noise and probability of achieving a specific SIR are derived. Section B discusses about the numerical simulation approach. where the performance is evaluated by repeated trial.

Section A:

Analytical Approach

1) Two Single Mode Lasers:

Optical centre frequency of each user's laser is assumed to be uniformly distributed over an optical channel of bandwidth 'D'. The PDF of Optical centre frequency

$$p_{f_i}(f) = \begin{cases} 1/D & f_{o_i} - D/2 < f < f_{o_i} + D/2 \\ 0 & \text{elsewhere} \end{cases} \tag{3.A.1}$$

f_{o_i} are mean of distribution of i^{th} centre frequenies of the two laser's fields then, $\delta f \triangleq f_1 - f_2$. Making use of the independence of f_1 and f_2, PDF of difference frequency δf is given by [12].

$$\begin{aligned} p_{\delta f}(\delta f) &= \int_{-\infty}^{\infty} p_{f_1}(\delta f + f_2) p_{f_2}(f_2)\, df_2 \\ &= \begin{cases} 1/D - \delta f/D^2 & \delta f > 0 \\ 1/D + \delta f/D^2 & \delta f < 0 \end{cases} \end{aligned} \tag{3.A.2}$$

a) Lorentian spectra:

The lasers are assumed to have lorentian spectral shape. From the results derived earlier in Chapter2 power spectrum of interference noise,

$$F(\delta f) = \frac{2}{(\pi \Delta f)}\left[1 + \left(\frac{2\ \delta f}{\Delta f}\right)^2\right]^{-1} \qquad (3.A.3)$$

where Δf is the spectral width of noise spectrum which equals sum of spectral widths of two sources i.e., $\Delta f = \Delta f_1 + \Delta f_2$ and δf is the optical frequency difference of two sources.

For the calculation of PDF of interference noise's power spectrum, $p_F(F)$ fundamental theorm is used. [PAPOULIS] In the intermediate stage, Eq. $F = G(\delta f)$ is solved to find the real roots δf_i's for a specific value of F. Thus,

$$\delta f = \pm \frac{\Delta f}{2} \sqrt{\frac{2}{(\pi \Delta f)} - 1} \qquad (3.A.4)$$

$$p_F(F) = \frac{p_{\delta f}(\delta f_1)}{|G'(\delta f_1)|} + \frac{p_{\delta f}(\delta f_1)}{|G'(\delta f_1)|} \qquad (3.A.5)$$

denoting $k_1 \triangleq \left[\dfrac{2}{(\pi\Delta f)}\right]$ and $k_2 \triangleq \left[\dfrac{2}{\Delta f}\right]$

$$G'(\delta f) = \frac{k_1 . \ -2. k_2{}^2 \delta f}{[\ 1 + (k_2 \delta f)^2]^2} . \qquad (3.A.6)$$

Using (3.A.6), (3.A.2) in (3.A.5)

$$P_F(F) = \frac{1/D - \delta f/D^2}{\left|\dfrac{k_1 . \ -2. k_2{}^2 \delta f_1}{[\ 1 + (k_2 \delta f_1)^2]^2}\right|} + \frac{1/D + \delta f/D^2}{\left|\dfrac{k_1 . \ -2. k_2{}^2 \delta f_2}{[\ 1 + (k_2 \delta f_2)^2]^2}\right|}$$

$$= \frac{[\ 1 + (k_2 \delta f_1)^2]^2 .}{k_1 \ k_2^2 \ \delta f_1} (1/D - \delta f/D^2) \qquad (3.A.7)$$

Using relations $F = \dfrac{k_1}{[\ 1 + (k_2 \delta f_1)^2]}$ and $\delta f_1 = \dfrac{1}{k_2}\sqrt{\dfrac{(k_1 - F)}{F}}$

$$P_F(F) = \left(\frac{k_1}{k_2^2 D}\right)\left(\frac{1}{F\sqrt{F(k_1 - F)}} - \frac{1}{F^2 D}\right) \qquad (3.A.8)$$

Calculation of Probability of Signal to Interference Noise Ratio:

SIR expression is given by

$$SIR = 10 \log \left[\frac{\frac{1}{2}\langle m_i(t)^2 \rangle}{F(\delta f)B} \right] \qquad (3.A.9)$$

where B is bandwidth of message and $F(\delta f)$ is power spectrum of interference noise. Assuming 100% modulation depth,

$$SIR = 10 \log \left[\frac{\frac{1}{2}}{F(\delta f)B} \right] \qquad (3.A.10)$$

For calculation of $p_{SIR}(SIR)$ the fundamental theorm is used. i.e., if $SIR = H(F_1)$ where F_1 is a real root then,

$$p_{SIR}(SIR) = \frac{P_F(F_1)}{|H'(F_1)|} \qquad (3.A.11)$$

$$\text{where} \quad F_1 = \frac{10^{-SIR/10}}{2.B} \qquad (3.A.12)$$

$$|H'(F_1)| = \frac{10 \log_{10} e}{F_1} \qquad (3.A.13)$$

Using Eq. (3.A.8) and (3.A.12) ,(3.A.11) can be written as

$$P_{SIR}(SIR) = \frac{\left(\dfrac{k_1}{k_2^2 D}\right)\left(\dfrac{1}{F_1\sqrt{F_1(k_1-F_1)}} - \dfrac{1}{F_1^2 D}\right)}{\dfrac{10\log_{10}e}{F_1}} \tag{3.A.14}$$

Achievability of a specific SIR is given by,

$$\text{Achievability} = \left\{ \frac{\text{Area under PDF curve so that SIR} \geq \text{SIR specific}}{\text{Total area} = 1} \right. \tag{3.A.15}$$

b. Gaussian spectra:

The lasers are assumed to have Gaussian power spectra. The power spectra of interference noise is given by,

$$F(\delta f) = \frac{13.33}{8\Delta f\sqrt{\pi}} \exp\left[-\left(\frac{2.0\ \delta f}{1.2\ \Delta f}\right)^2\right]. \tag{3.A.16}$$

where spectral width of noise spectrum $\Delta f = \sqrt{(\Delta f_1)^2 + (\Delta f_2)^2}$ Δf_i are spectral width of each of sources, and δf is the optical frequency difference of two sources.

Defining $\quad k_1 \triangleq \dfrac{13.33}{8\Delta f\sqrt{\pi}} \quad \& \quad k_2 \triangleq \left(\dfrac{2.0}{1.2\ \Delta f}\right)$

To find, $p_F(F)$ for a specific F, equation $F = G(\delta f)$ is solved.

$F = G(\delta f_1) = G(\delta f_2)$ where the real roots are given by,

$$\delta f_{1(2)} = \pm \frac{1}{k_2}\sqrt{\ln\left[\frac{k_1}{F}\right]} \tag{3.A.17}$$

From fundamental theorm,

$$p_F(F) = \frac{p_{\delta f}(\delta f_1)}{|G'(\delta f_1)|} + \frac{p_{\delta f}(\delta f_2)}{|G'(\delta f_2)|} \tag{3.A.18}$$

$$G'(\delta f) = k_1 e^{-(k_2 \delta f)^2} . -k_2^2 . 2\delta f$$

$$= -k_2 . 2F . \sqrt{\ln\left(\frac{k_1}{F}\right)} \tag{3.A.19}$$

Using Eq. (3.A.2) in (3.A.18)

$$p_F(F) = \frac{\left(1/D - \delta f_1/D^2\right)}{|G'(\delta f_1)|} + \frac{\left(1/D + \delta f_2/D^2\right)}{|G'(\delta f_2)|} \tag{3.A.20}$$

Using Eq.(3.A.19) & (3.A.17) in (3.A.20) and since $\delta f_1 = -\delta f_2$

$$P_F(F) = \frac{1}{K_2 DF}\left[\frac{1}{\sqrt{\ln\left(\frac{k_1}{F}\right)}} - \frac{1}{K_2 D}\right] \tag{3.A.21}$$

Calculation of Probability of Signal to Interference Noise Ratio:

SIR expression assuming 100% modulation depth is given by

$$SIR = 10 \log \left(\frac{\frac{1}{2}}{F(\delta f)B}\right) \tag{3.A.22}$$

where B is bandwidth of message and $F(\delta f)$ is power spectrum of interference noise.

For calculation of $p_{SIR}(SIR)$ fundamental theorm is used. i.e., if $SIR = H(F_1)$ where F_1 is a real root then,

$$p_{SIR}(SIR) = \frac{p_F(F_1)}{\left|H'(F_1)\right|} \tag{3.A.23}$$

$$\text{where} \quad F_1 = \frac{10^{-SIR/10}}{2.B} \tag{3.A.24}$$

$$|H'(F_1)| = \frac{10 \log_{10} e}{F_1} \qquad (3.A.25)$$

Using Eq. (3.A.21) & (3.A.25) , Eq. (3.A.23) can be written as

$$P_{SIR}(SIR) = \frac{\dfrac{1}{K_2 DF}\left[\dfrac{1}{\sqrt{\ln\left(\dfrac{k_1}{F}\right)}} - \dfrac{1}{K_2 D}\right]}{\dfrac{10 \log(e)}{F}}$$

$$= \frac{\ln(10)}{10.\ K_2 D}\left[\frac{1}{\sqrt{\ln\left(\dfrac{k_1}{F}\right)}} - \frac{1}{K_2 D}\right] \qquad (3.A.26)$$

The achievability is calculated as in the case of lorentian spectra.

2. Case of 2 Multimode lasers, individual modes Lorentian and envelope Gaussian:

Here the case two Multimode Lasers each having 3 Modes, the centre frequency of the laser being uniformly distributed over a band of 'D' is considered. For each Laser, mode separation is given by 'L'.

The amplitude levels of the modes of 2 lasers are A_1, A_2, A_3. Computation for power spectrum of interference noise is done taking into account all the combinations. Suppose F_0 represents contribution due to mixing of electric fields of similar modes (i.e., mode1 of laser1 with mode1 of laser 2 etc.,), then

$$F\_0 = a\_0 \times \frac{k_1}{[1 + k_2^2 \delta f^2]} \qquad (3.A.27)$$

where δf is separation frequency of lasers and

$$a\_0 \triangleq \frac{\Sigma A_i \cdot A_i}{\Sigma A_i \cdot \Sigma A_i} \qquad (3.A.28)$$

Suppose F_L represents contribution due to mode pairs of 1,2 & 2,3; (where the first and second numbers are the modes of laser 1 and laser 2 respectively), then

$$F\_L = a\_L \times \frac{k_1}{[1 + k_2^2(\delta f + L)^2]} \qquad (3.A.29)$$

$$\text{where } a\_L \triangleq \frac{A_1 A_2 + A_2 A_3}{\Sigma A_i \cdot \Sigma A_i} \qquad (3.A.30)$$

Similarly F_ML which is contribution due to the modepairs of 2,1 and 3,2 is given by,

$$F\_ML = a\_L \times \frac{k_1}{[1 + k_2^2(\delta f - L)^2]} \qquad (3.A.31)$$

F_2L which is due to mode pair 1,3 is given by,

$$F\_2L = a\_2L \times \frac{k_1}{[1 + k_2^2(\delta f + 2L)^2]} \qquad (3.A.32)$$

$$\text{where } a\_2L \triangleq \frac{A_1 A_3}{\Sigma A_i \cdot \Sigma A_i} \qquad (3.A.33)$$

Similarly F_M2L which is due to mode pair 3,1 is given by,

$$F\_M2L = a\_2L \times \frac{k_1}{[1 + k^2(\delta f - 2L)^2]} \quad (3.A.34)$$

The power spectrum of total interference noise is given by

$$F = F\_O + F\_L + F\_ML + F\_2L + F\_M2L \quad (3.A.35)$$

For the calculation of PDF of interference noise's power spectrum, $p_F(F)$ fundamental theorm is used.

$$p_F(F) = \frac{p_{\delta f}(\delta f_1)}{|G'(\delta f_1)|} + \frac{p_{\delta f}(\delta f_2)}{|G'(\delta f_2)|} \quad (3.A.36)$$

where δf_1 & δf_2 are the real roots of eqn., $F = G(\delta f)$

Taking derivative wrt δf,

$$G'(\delta f) = \frac{-2.0 \cdot k_2^2}{k_1}\left[\frac{F\_O^2.\delta f}{a\_O} + \frac{F\_L^2.(\delta f + L)}{a\_L} + \frac{F\_ML^2(\delta f - L)}{a\_L} + \right.$$

$$\left. \frac{F\_2L^2.(\delta f + 2L)}{a\_2L} + \frac{F\_M2L^2.(\delta f - 2L)}{a\_2L}\right] \quad (3.A.37)$$

Since, $\delta f_1 = -\delta f_2$, & $|G'(\delta f_1)| = |G'(\delta f_2)|$

$$p_F(F) = \frac{2 \times \left[\frac{1}{D} - \frac{\delta f}{D^2}\right]}{|G'(\delta f)|} \qquad (3.A.38)$$

From Eq. (3.A.23) & (3.A.25), probability of specific SIR,

$$p_{SIR}(SIR) = \frac{p_F(F)}{\left[\frac{10 \log_{10} e}{F}\right]} \qquad (3.A.39)$$

Procedure for getting achievability:

$p_{SIR}(SIR)$ is calculated choosing different sample values of difference frequencies. Then from the points got, Lagrange interpolation is done to get the curve. Integration is done to get the area such that SIR exceeds a specific choosen SIR. Achievability is given by,

$$\text{Achivability} = \frac{\text{Area s.t., SIR} \geq \text{SIR\_specific}}{\text{Total area} = 1} \qquad (3.A.41)$$

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Section B:

SIMULATION APPROACH.

In this approach, probability of interference noise and hence probability of achieving a given signal to noise ratio are determined by numerical simulations.

1) Single Mode Lasers:

The centre frequencies of the two Lasers are assumed to be distributed uniformly over a band of 'D'. The power spectrum shape may be Lorentian or Gaussian.

Random numbers corresponding to the centre frequencies of lasers are generated and difference frequency and hence SIR is got. This experiment is repeated a large no., of times. For getting achievability of a specific SIR, following formula is used.

$$\text{Achievability} \triangleq \frac{\text{No., of trials SIR} \geq \text{SIR\_specific}}{\text{Total no., of trials}} \qquad (3.B.1)$$

2) Two Multimode Lasers:

Here the case of 2 multimode lasers each having 3 modes, centre frequency of each laser being uniformly distributed over the specified band is considered. A uniform distribution random number

generator is used to get the number corresponding to centre frequencies of lasers. As outlined in section A.2 power spectrum of interference noise is got and hence SIR is calculated. A large number of trials are taken, at each trial SIR is calculated. Achievability is obtained by using the Eq. (3.B.1).

3) N number of Multimode Lasers:

In this subsection the problem of evaluating system performance when N multimode lasers are simultaneously transmitting is discussed. The centre frequency of each laser is assumed to be uniformly distributed over a band of 'D'. Each laser is assumed to have 3 modes the levels of which are 0.75, 1 & 0.75. As in the 2 laser cases a pseudorandom number generator is employed to get the centre frequencies of each laser. At each step the SIR is evaluated. Eq. (3.B.1) is used to get the achievability of a choosen SIR. Above set of experiments are repeated for different laser numbers.

Number of modes of the laser affects considerably the optical interference noise as stated in chap2 sec D. To study the effect of this on SIR, it is varied and SIR_achievable i.e., SIR_a is computed.

Since the linewidth of longitudinal modes effectively determines the bandwidth of interference spectrum, linewidth is varied to study its effect on SIR_a.

Section C:

Result and Discussions:

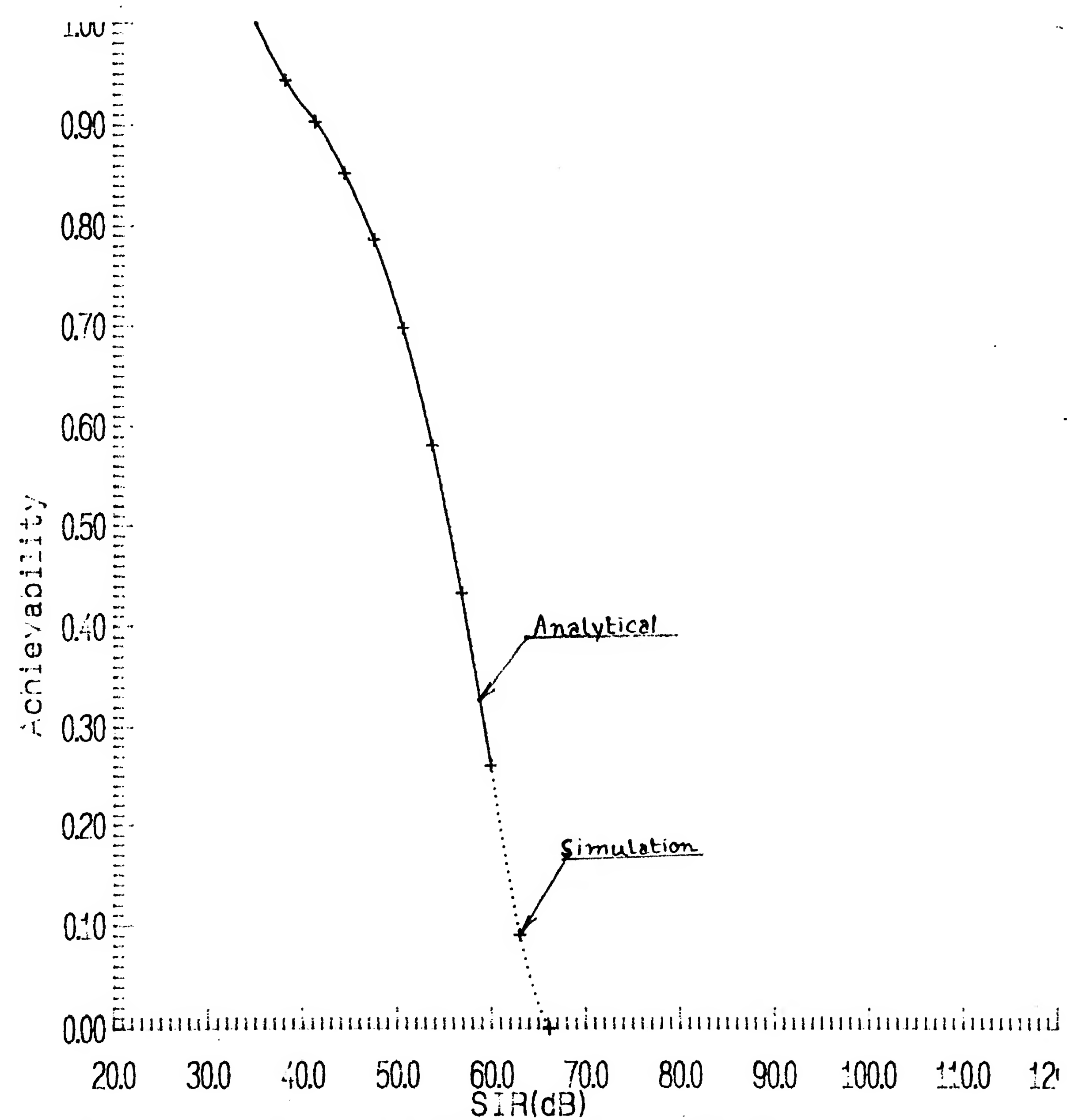
Fig. 7 & 8 show the comparitive curves for the results from analytical approach and simulation for the case of single mode Lorentian and Gaussian spectra respectively. Fig. 9 shows the same curves for the 2 multimode lasers each having 3modes. It is seen that higher is the SIR lower is the achievability. In all the three graphs the curves obtained from analytical approach and simulation are almost similar.

Fig. 10 shows the achievability vs SIR_a in 5MHz bandwidth with number of lasers as parametre. It is seen that as the number of laser increases achievability curve shifts to the left indicating lesser SIR_a. This is due to the increase of noise as the laser number increases.

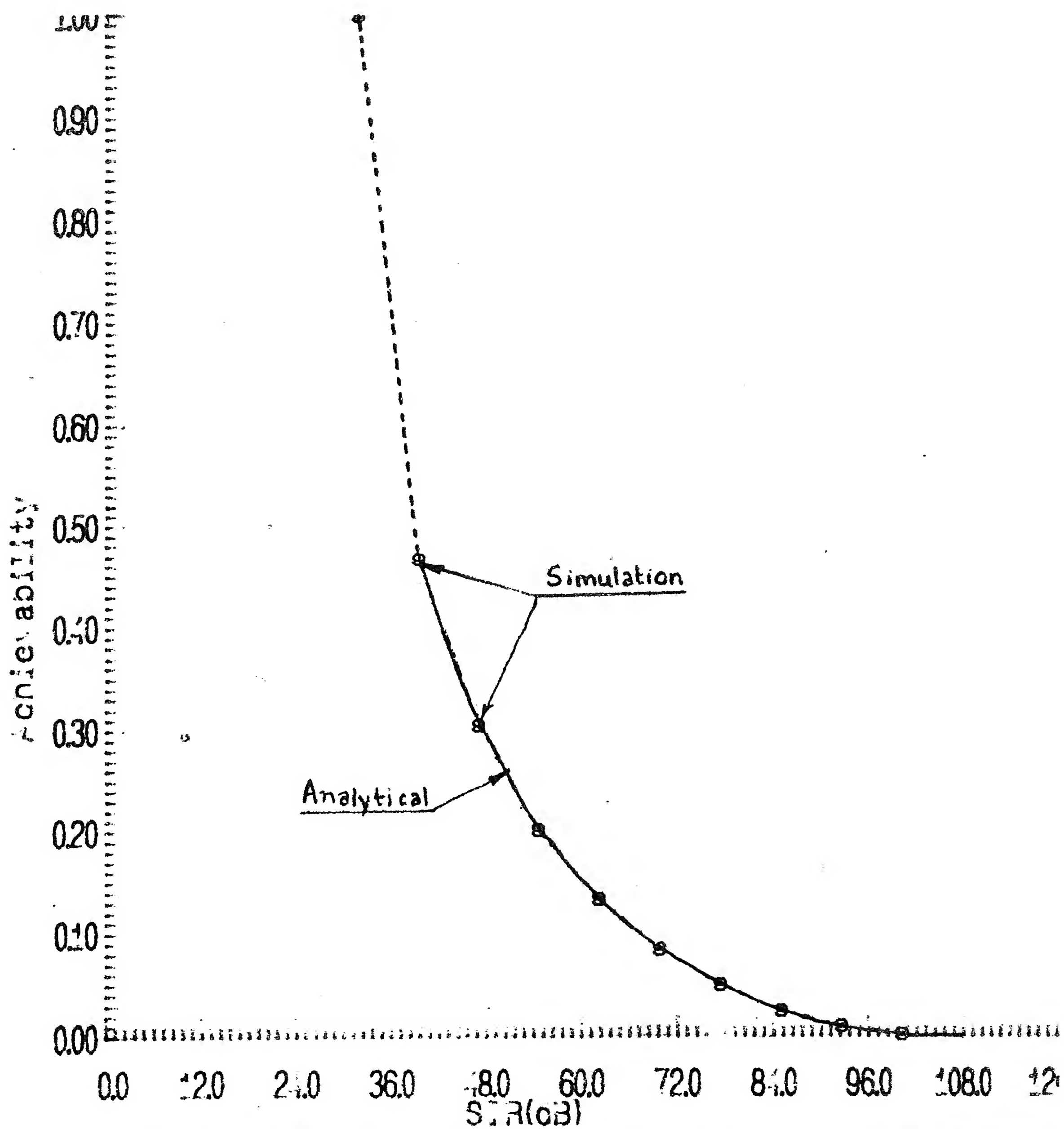
Fig(11) shows the variation of SIR_a as the number of longitudinal modes varies. The increasing behaviour of SIR_a can be attributed to the fact that the modes contribute to the total

interference noise on a power basis, since the mode fields are assumed to be uncorrelated.

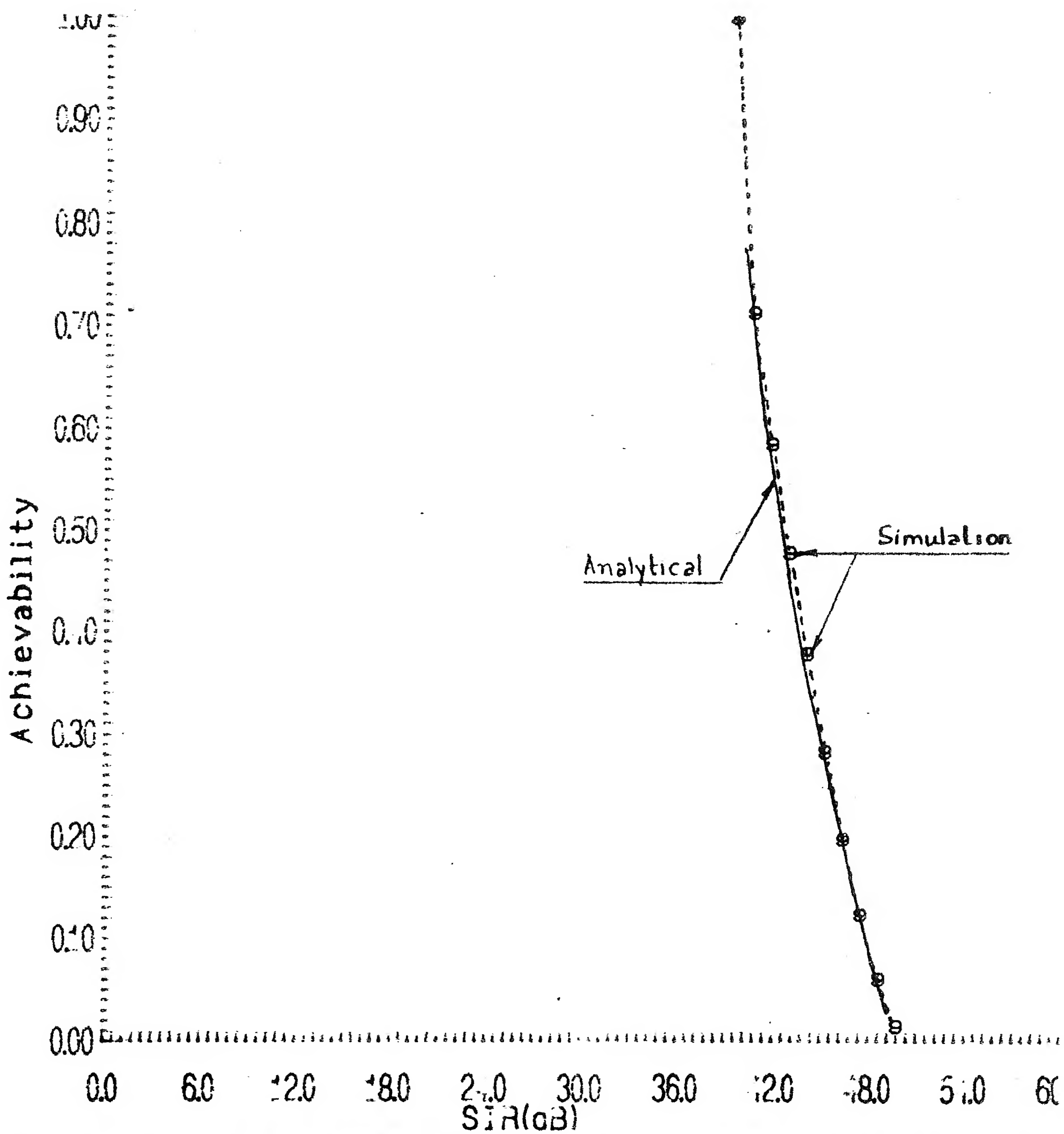
Fig.(12) shows the variation of SIR_a as the linewidth of the individual modes change. As the linewidth increases, the same power gets distributed over a larger band, and hence a reduction of interference noise within the band occurs. Hence as the linewidth increases SIR_a increases.



SIMULATION AND ANALYTICAL APPROACH COMPARISON MONOMODE LORENTIAN SPECTRA

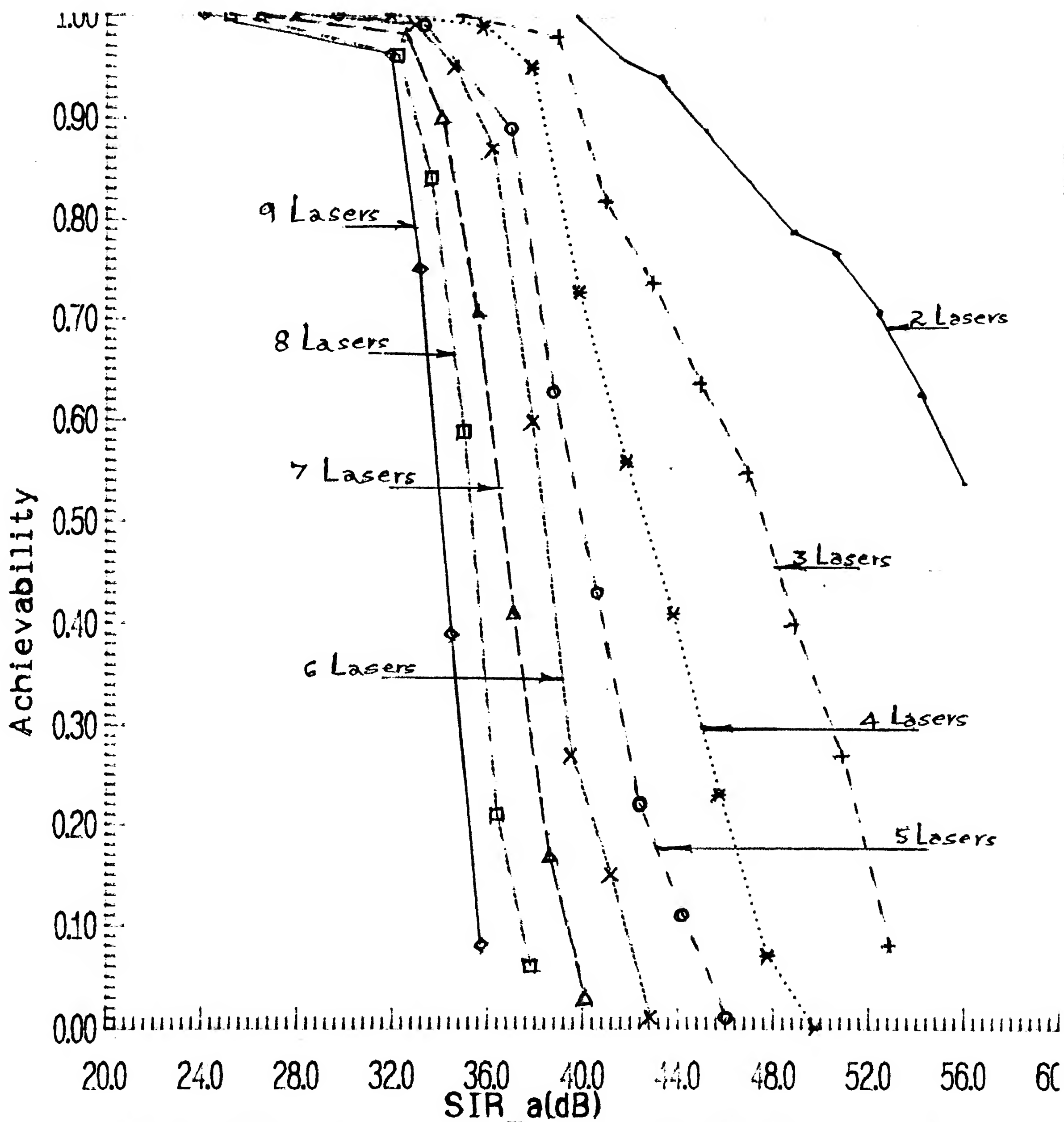


SIMULATION AND ANALYTICAL APPROACH COMPARISON
MONOMODE GAUSSIAN SPECTRA

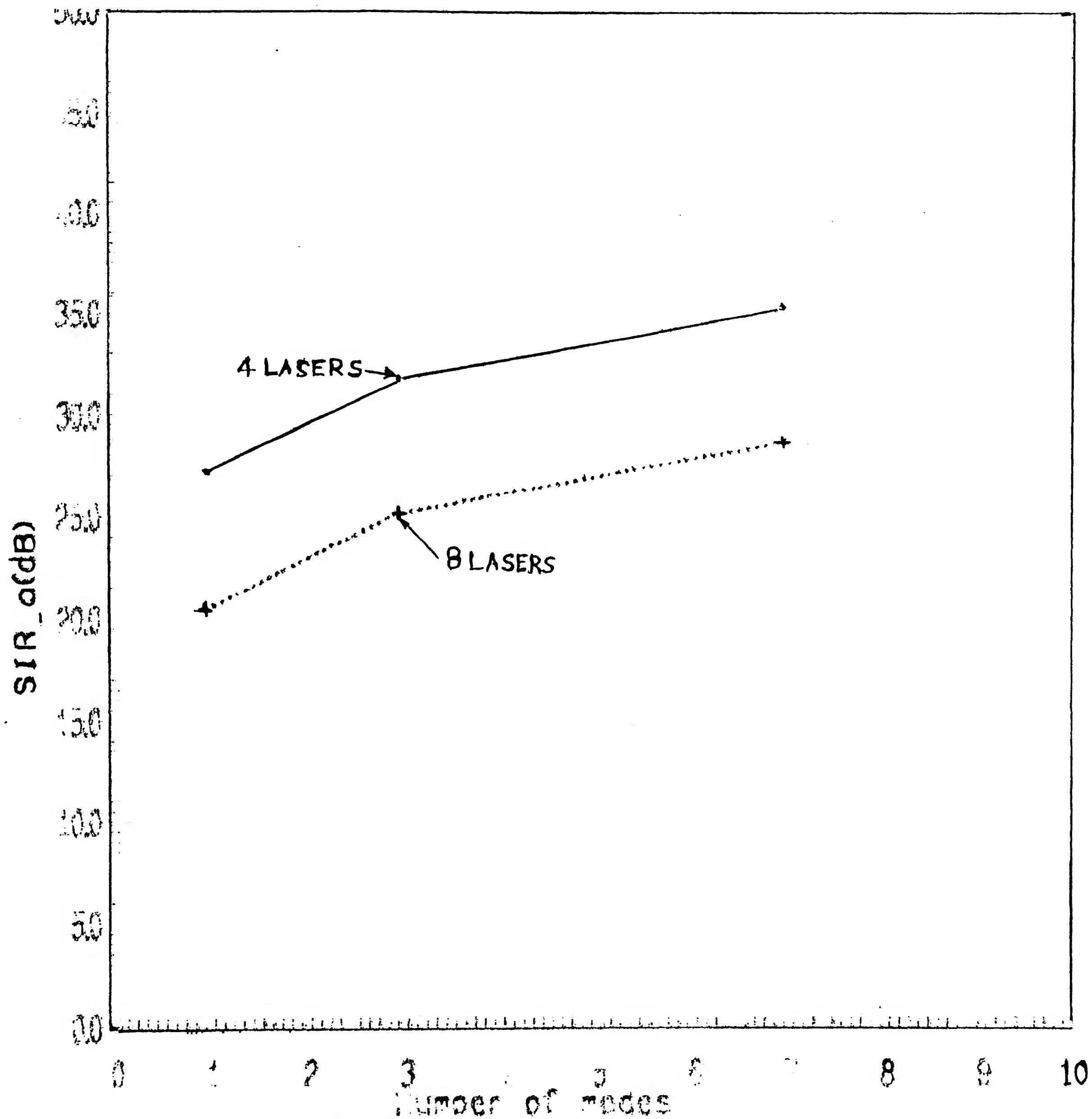


SIMULATION AND ANALYTICAL APPROACH COMPARISON 3MODE LASERS

Fig. 9

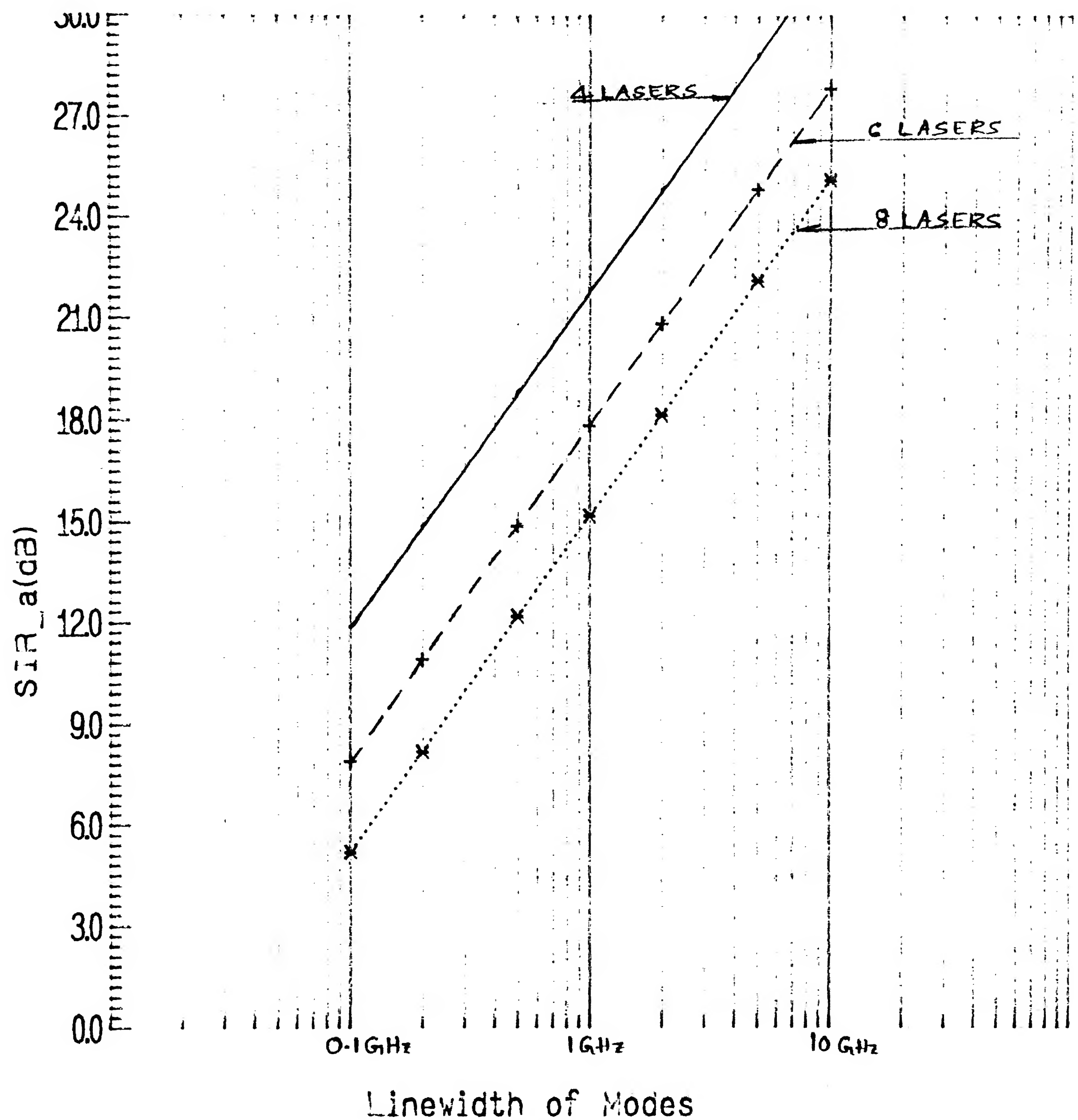


ACHIEVABILITY VS SIR_a WITH NUMBER OF LASERS AS PARAMETRE



VARIATION OF SIR_a WITH NUMBER OF MODES

Fig. 11



VARIATION OF SIR_a WITH LINEWIDTH OF MODES

CHAPTER 4

CONCLUSION AND SCOPE FOR FUTURE WORK

It was noted that the interference noise limits the maximum number of channels or the bandwidth of the SCM system. Results of statistical analysis point out that by using Lasers having larger number of longitudinal modes or larger linewidth Laser better performance can be got. Also by selecting lasers carefully so that their wavelengths are different, interference noise effect can be minimised.

While deriving formulas for power spectrum of interference noise in Chapter 2, it is assumed that the message bandwidth is negligible compared to the optical source linewidth. Evaluation of power spectrum of interference noise, when message bandwidth is comparable to optical source linewidth will be an interesting problem to be tackled.

It was observed that the analytical approach and simulation results tallied almost exactly for the case of 2 single mode lasers for both Lorentian and Gaussian spectral shaped and also 2 multimode lasers. It was assumed that the lasers are intensity modulated. There is need for similar analytical approach to be

developed to evaluate the performances of the systems with N single mode and N multimode lasers. At present, their performances can be studied only by simulations. It will be interesting to attempt the analyses in those cases which are more complicated. It will be of interest to know the applicability of analytical approach to the more complicated methods of modulation.

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